pA Physics in STAR

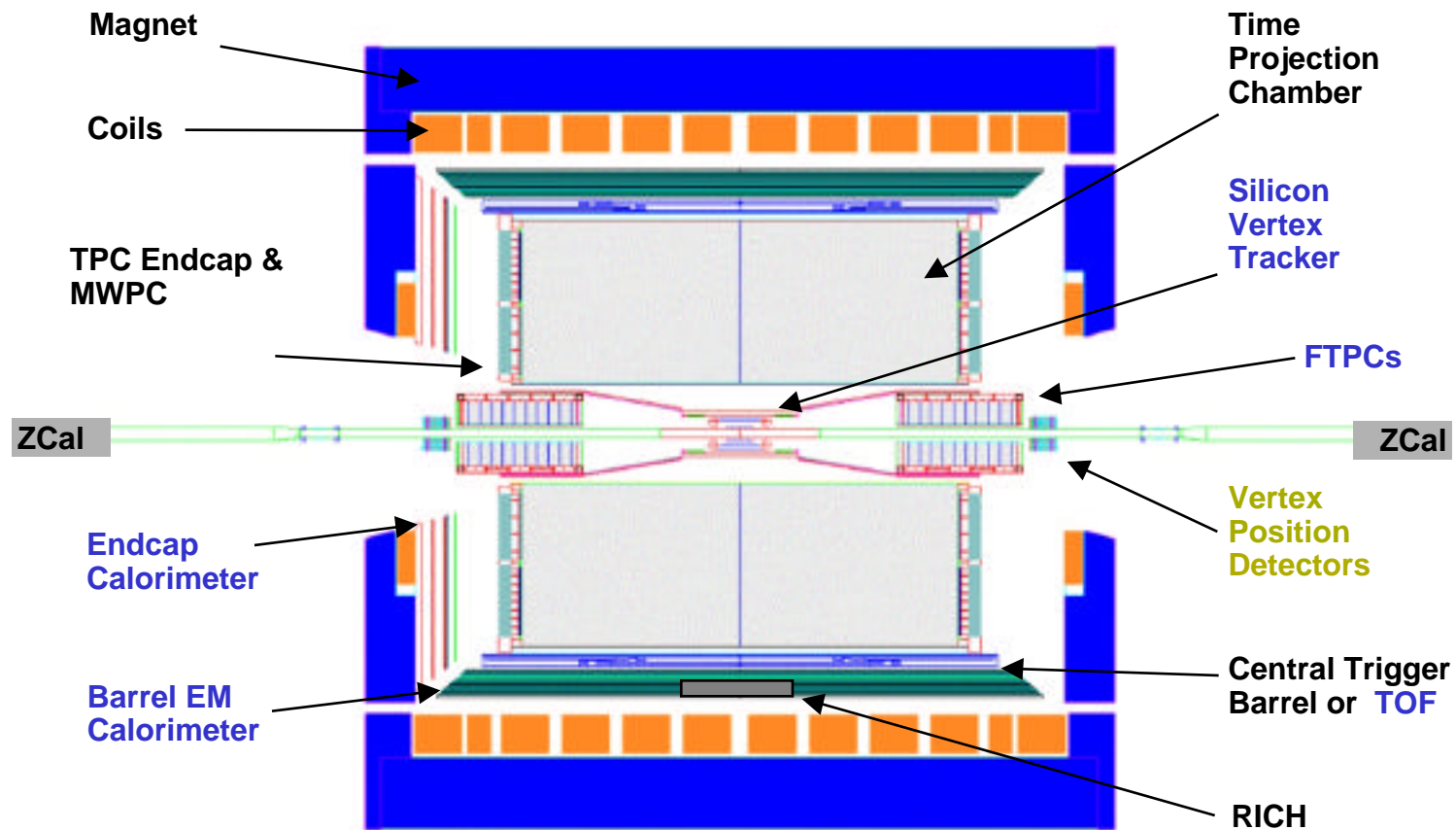*Peter Jacobs, LBNL*
for the STAR Collaboration

- STAR detector and pA-related observables
- pA and AA physics
- Gluon Distributions in Nuclei
- Event Characterization in pA
- STAR upgrades relevant to pA
- Summary

Preliminary remarks

- pA physics is often mentioned as part of STAR experimental program
- Some individual pA studies (G. Odyniec, H. Huang) but until now no formal framework within collaboration
- pA at RHIC is of broad interest:
  - Fundamental study of QCD
  - Isolation of nuclear effects to interpret AA data
- I will present some thoughts on pA in STAR
  - Not yet a proposal for an experimental program
  - Many open questions

  Aim of this talk: set scale of pA program, identify some important issues for STAR to address

The STAR Detector

Magnet

Coils

TPC Endcap & MWPC

Endcap Calorimeter

Barrel EM Calorimeter

ZCal

Time Projection Chamber

Silicon Vertex Tracker

FTPCs

Vertex Position Detectors

Central Trigger Barrel or TOF

RICH

ZCal

RICH replaced by final EMC modules in '03

STAR Institutions

U.S. Labs:

Argonne, Berkeley, and Brookhaven National Labs

U.S. Universities:

Arkansas, UC Berkeley, UC Davis, UCLA, Carnegie Mellon, Creighton, Indiana, Kent State, MSU, CCNY, Ohio State, Penn State, Purdue, Rice, Texas A&M, UT Austin, Washington, Wayne State, Yale

Brazil:

Universidade de Sao Paolo

China:

IHEP - Beijing, IPP - Wuhan

England:

University of Birmingham

France:

Institut de Recherches Subatomiques Strasbourg, SUBATECH - Nantes

Germany:

Max Planck Institute – Munich
University of Frankfurt

Poland:

Warsaw University
Warsaw University of Technology

Russia:

MEPHI – Moscow, LPP/LHE JINR – Dubna, IHEP - Protvino

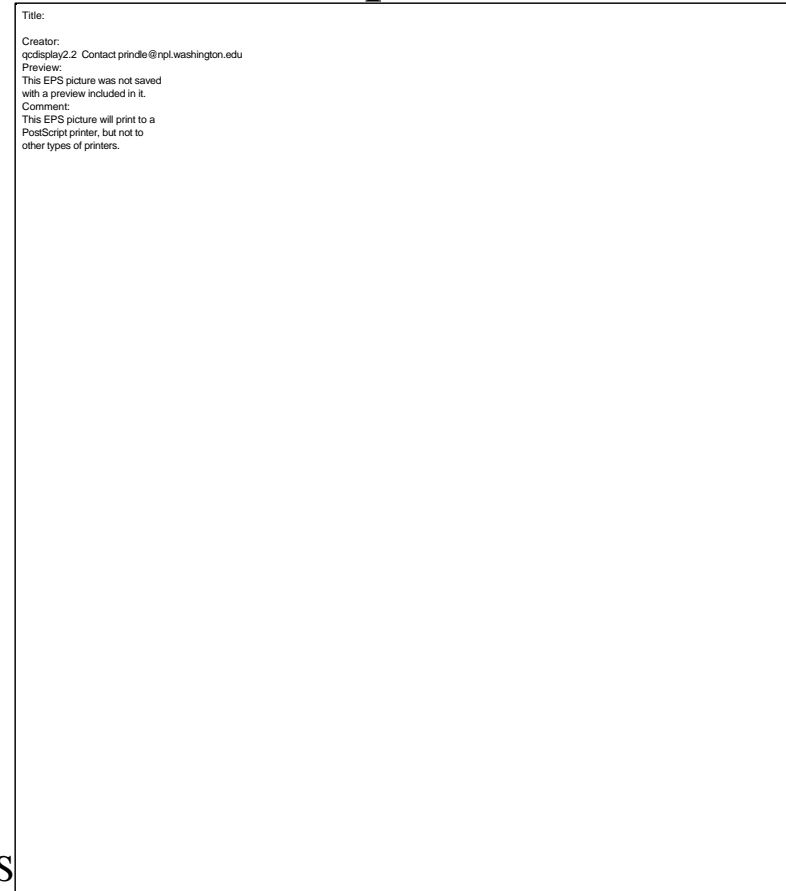# Offline Reconstruction (Au+Au at 130 GeV)
(modest multiplicity shown so details are visible)

All hits on tracks:
- red = low pT
- violet = high pT

Hits not assigned to tracks: mostly noise and low momentum spirals

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qcdisplay2.2 Contact prindle@npl.washington.edu
Preview:
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with a preview included in it.
Comment:
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PostScript printer, but not to
other types of printers.

Title:

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other types of printers.

Barrel EM Calorimeter

- Coverage: $-1 < \eta < 1$

- 4800 lead-scintillator projective towers (18 X_0)

- each tower $\Delta\eta$ x $\Delta\phi$ =0.05 x 0.05

- resolution $\Delta E/E = 16\%/\sqrt{E}$

- preshower (factor 4 hadron rejection for electrons)

- gas-filled shower max at 5X_0:
  - 36000 channels
  - resolve photons from π^0 at 25 GeV

Endcap EM Calorimeter

- Coverage: $1.07 < \eta < 2$

- 720 lead-scintillator projective towers (21 X_0, sampling fraction 6.6%)

- towers $\Delta\eta \times \Delta\phi = 0.05\text{-}0.10 \times 0.10$

- resolution $\Delta E/E \sim 14\%/\text{sqrt}(E)$

- preshower (factor 4 hadron rejection for electrons)

- scintillator shower max at $5X_0$:

  - 7200 channels

  - rejects 80% of π^0s with 80% photon efficiency at 30 GeV

General Remark on Calorimetry

- Calorimeters are essential for triggering on high pT jets, hadrons (π^0), photons and electrons

- Important fact: installation schedule:
  - Barrel: 25% per year from FY01 to early FY04
  - Endcap: 50% FY02, 50% FY03

- High p_T component of pA in STAR requires calorimeter
  Extended pA running only makes sense starting in '03

Main STAR Observables for pA

- Charged particles to high p_T (~15 GeV)
- ^{0}, to high p_T
- Jets: inclusive, coincidence
- Identified hadrons
  - /K/p/… via dE/dx in TPC (p<1 GeV)
  - topological PID (K^+, K^-, K^0_s, , bar, , ,…)
    - in some cases, pT ~ several GeV
  - Resonances
- J/ e+e-, D K

Physics topic 1: Jets in AA and pA

- Energy loss dE/dx of high energy partons in medium is sensitive to energy density
- dE/dx via gluon brehmsstrahlung: jet fragmentation profile changes (softens)
- Energy loss in AA measured in STAR via:
  - High p_T hadron inclusive spectra+coincidences (pi0, charged hadrons)
  - Flavor tagging (leading K+/K-, / bar, p/pbar) quark/gluon differential energy loss
  - Gamma/jet coincidence: photon is non-interacting "standard candle"
  - ("flow" of high pT hadrons wrt reaction plane)

Jets in AA and pA (cont'd)

- Initial state effects also influence jet/hadron spectrum:
    - shadowing
    - generation of k_T via multiple soft interactions

- X.N. Wang et al.:
    - pp and pA measurements may isolate initial state effects
    - pp and pA data are essential to interpret AA data

Physics topic 2: Inclusive Hadron Spectrum

AA: pT distribution of hadrons
influenced by multiple
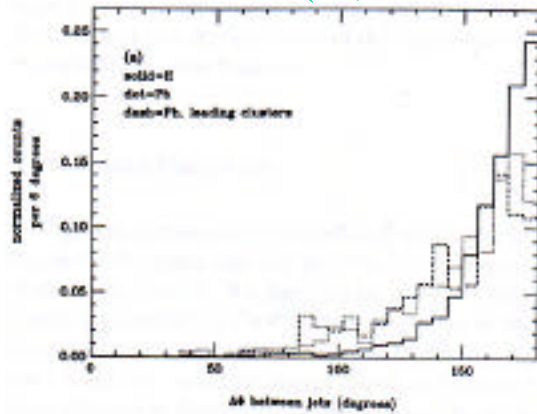scattering and radial flow

pA: multiple scattering only (+shadowing)
Rough estimate of hadron yield limits
(~100 counts/GeV, 10 weeks of p+Au):
pions to p_T >15 GeV/c; Kaons to p_T >12
GeV/c;   /   bar to p_T ~10 GeV/c
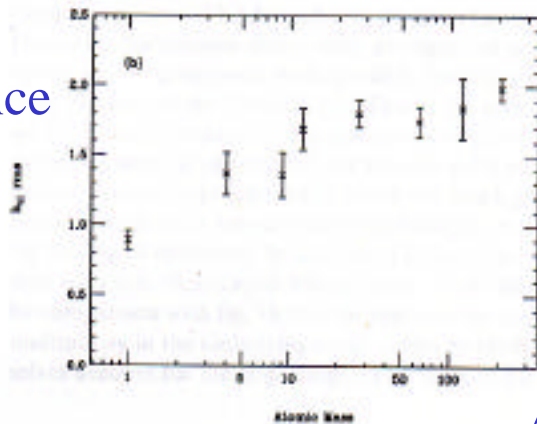   Topological PID in TPC: how high in
p_T?

pA/A pp

"Cronin" effect

1

5   10 p_T
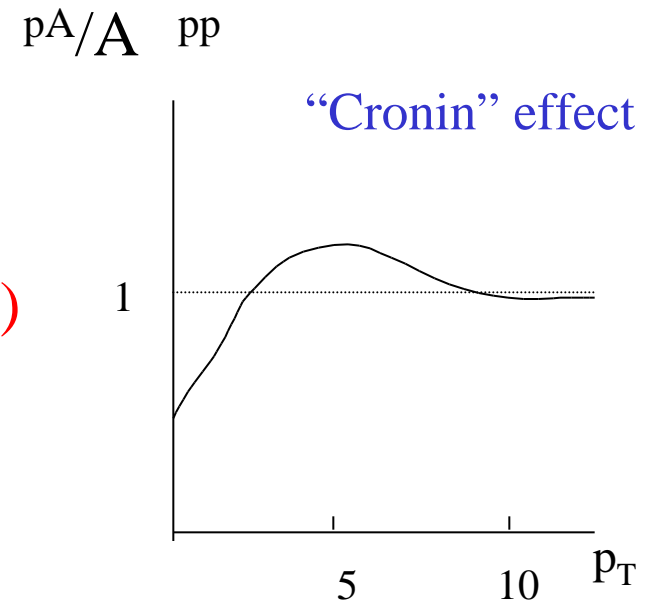
Physics topic 3: Multiple Scattering via Dijets in pA

Angular correlations (H, Pb)

(jet-jet)

k_T mass dependence

A

- E609: dijet acoplanarity due to multiple scattering
- Larger effects in Pb than H in
  - fitted k_T
  - acoplanarity
- High quality measurements look possible in STAR (but not yet studied):
  - Robust dijet yields
 - Good dijet acceptance, energy resolution

Physics topic 4: Charm in AA and pA

- AA collisions: J/ψ suppression is important signature of deconfinement (Debye screening)
- STAR will measure:
  - J/ψ → e^+e^- (low x_F)
  - D → K
- Fermilab E866: J/ψ measured in pA
  - suppression at all x_F (α~0.95 @ x_F~0)
  - p_T dependence consistent with multiple scattering
- Charm measurement in pA is essential to interpret AA data!
- A-dependence is important
- STAR: need to study J/ψ capabilities specific to pA

Physics topic 5: Soft hadrons in pA and AA

- pA is essential reference for AA soft physics: baryon stopping, strangeness enhancement, …
- No additional experimental preparation needed for pA (except trigger?)
- Modest statistics needed except for rare probes (e.g.   )
  - No event rate estimates done yet to set scale of program
  - Hard probes more demanding for beam time   soft physics will mostly be done along the way
- Systematics: A-dependence
- Energy scan at modest statistics?
- Event characterization?
- Minbias Triggering?

Physics topic 6: Measurement of Gluon Distribution in Nuclei

Au Shadowing in EKS98

Q = 7 GeV   10 GeV   15 GeV
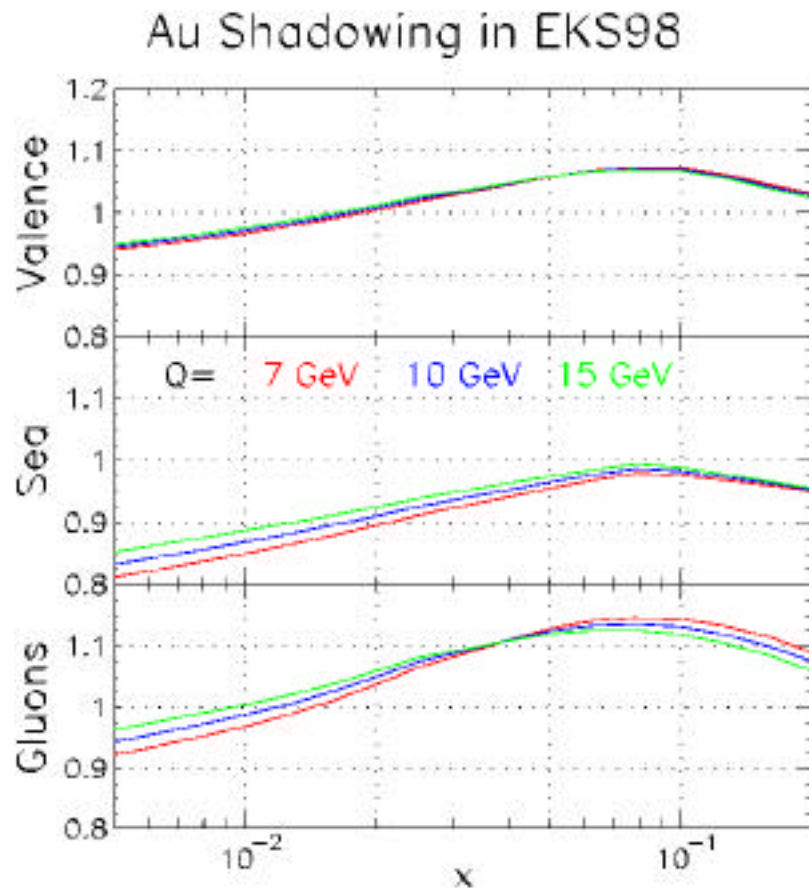
(Carl Gagliardi/E866)

- Effects are small (~10%) requires precision measurement
- STAR: Compton process q+g → q+γ
  - Dominates direct photon xsection (90%)
- Low x → asymmetric collision → EMC Endcap is essential

# Calculation of Statistical Precision of Direct Photon Measurement

- Hijing, p+Au @ sqrt(s)=200 GeV, p_T >10 GeV
- Integrated luminosity:
    - Sam Aronson: best guess is ~5×10^{28}/cm^2/sec
    - Assume 10 week run (probably generous), 75% duty factor   Integrated Luminosity ~ 2×10^5/μb
- STAR acceptance: Parton/ kinematics, no jet finding
    -     : -1< <2, jet: -0.5< <1.5
- Measure p_T ,   , ^{jet} x_1, x_2
- Assume $x_{gluon} = x_2$ ($< x_1$)

Why $p_T > 10$ GeV?

- In principle, small p_T interesting to access small x_{gluon}
- Instrumental issue: γ / π^0 too small at lower p_T
  - Result from pp (spin) studies, should be same in pA
- Theoretical issues:
  - Large fragmentation photon yield at smaller p_T
  - E706 effect: NLO not sufficient at $p_T < 10$ GeV (but what about collider kinematics – lower x_T?)
  - Additional k_T due to multiple scattering in nuclei: bigger relative effect at smaller p_T

  We restrict our discussion to $p_T > 10$ GeV

Statistical Precision for x1, x2 (10 week run, full EMC coverage)
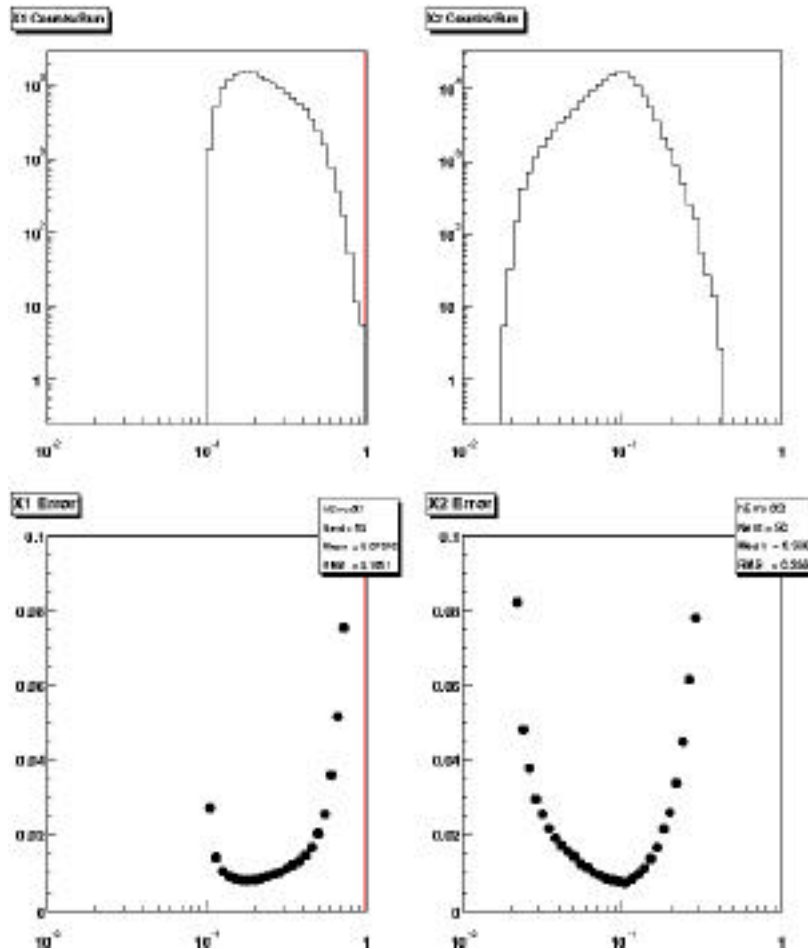
- Upper panels: counts per bin

- Lower panels: relative statistical error

  5% @ $x_2 \sim .02$

(sharply falling spectrum)

- 10 weeks needed for high quality measurement

- '02 run: partial EMC coverage

  5% @ $x_2 \sim .04$

Summary of Gluon Distribution Measurement

- From statistical point of view looks doable with ~10 weeks running per year per A

- Study A-dependence (3 masses?)   multiyear program

- Open experimental and theoretical issues:
  - γ / π^0

  - Fragmentation photon yields and isolation cuts

  - resolutions

  - Luminosity monitoring (Sebastian's talk):
    - Van der Meer scan? Other ideas?

Event characterization in pA

- Tantalizing prospect: vary thickness of target via tagging of collision geometry (# excited target nucleons)
- Famous problem in fixed target: measure "grey" protons (Brian Cole's talk)
  - Very tough to measure in collider mode
- Alternative: charged multiplicity in e.g. $-3< <3$
  - Correlation with # excited target nucleons not bad (see next slide)
- Another alternative: multiplicity in e.g. Li+Au
  - Advantage: correlation w/ geometry significantly better
  - Disadvantage: "dirty" probe for high precision work
  - But how dirty? Needs some study

Characterization of Geometry via Charged Multiplicity

z axis is logarithmic
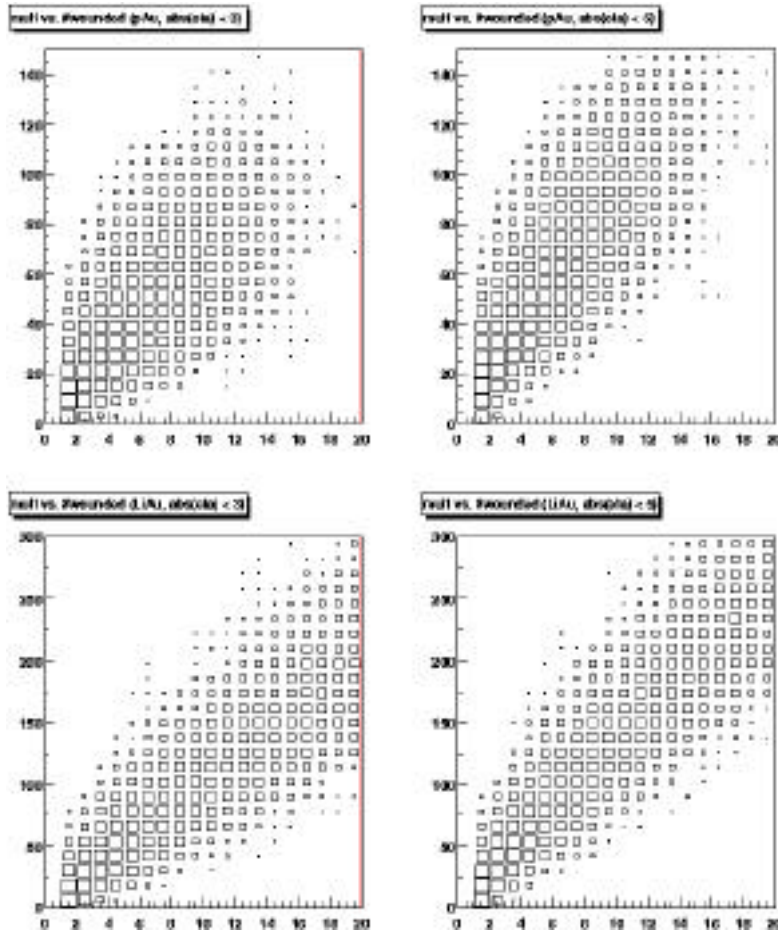
- Hijing minbias @200 GeV for p+Au, Li+Au

- Charged multiplicity within | |<3 and | |<5

- Multiplicity vs # wounded "target" nucleons

- correlation exists in p+Au good enough?

- correlation significantly sharper in Li+Au (note log scale in z)

STAR Upgrades relevant to pA

- High precision vertex tracker for D mesons $\to$ hadrons
- More forward coverage for yet lower x_{gluon}??
  - Low x measured by very asymmetric collisions $\to$ EMC Endcap
  - Consider even more forward calorimeter to get lower x_{gluon} (e.g. $3 < \eta < 5$ stacked around the beam pipe)
  - pT>10 GeV: unfortunately, cross sections are tiny $\to$ no rate
  - pT>5 GeV: plenty of rate, but unfavourable γ/π^0, interpretational problems

    Forget it!

Summary of pA Physics Topics

- Jets and high p_T hadrons:
  - pA essential to disentangle mult scattering effects
  - STAR has many observables, robust capabilities
- Charm:
  - Essential to measure J/   absorption in pA
  - STAR measures well at small xF
- Soft hadrons:
  - pA supplies essential reference, STAR has many channels
  - Energy scan, event characterization, triggering,…
- Gluon distributions in nuclei:
  - Probably doable statistically
  - Many experimental and theoretical issues

Conclusions

- pA is a major program at RHIC
    - Important to measure A-dependence
    - Several weeks of running per year over several years

- General experimental issues: trigger, luminosity monitoring,…
- STAR: extended pA running should begin '03 (driven by calorimeter installation schedule)

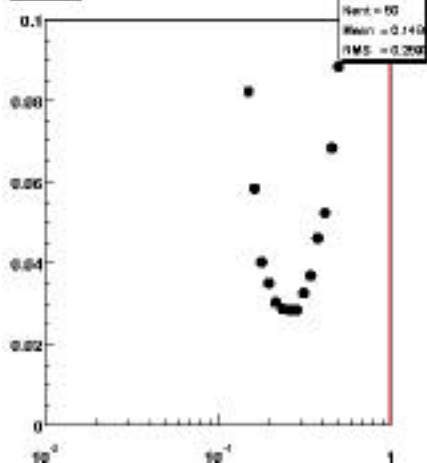# Statistical Precision for x1,x2 with "year '02" EMC coverage
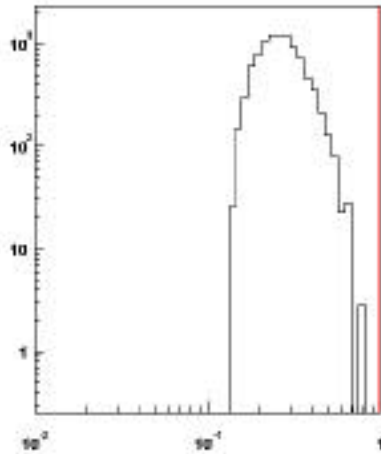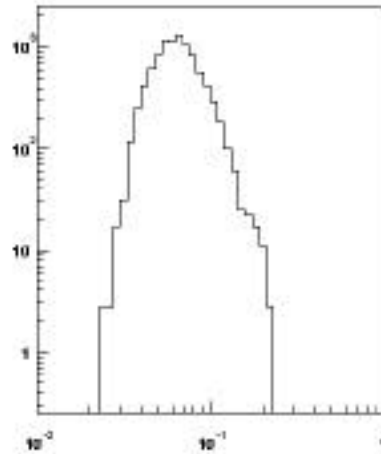
- Barrel:
  - 0< <1
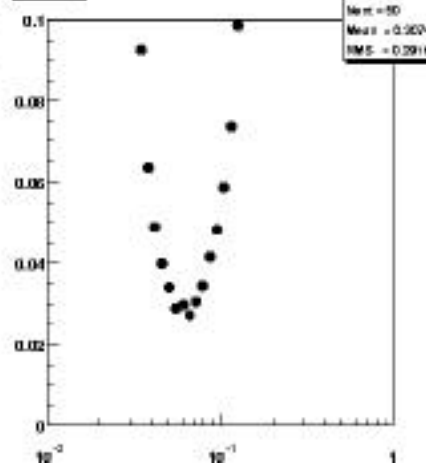 - 0< <2

- Endcap:
  - 1< <2
  - 0< <

BNL, Oct 28,2000   pA Physics in STAR

Track Reconstruction

Position resolution (cosmic rays)

sigma x (cm)

Outer sector

Inner sector

~ 500 µm

crossing angle

Reconstructed Laser Event
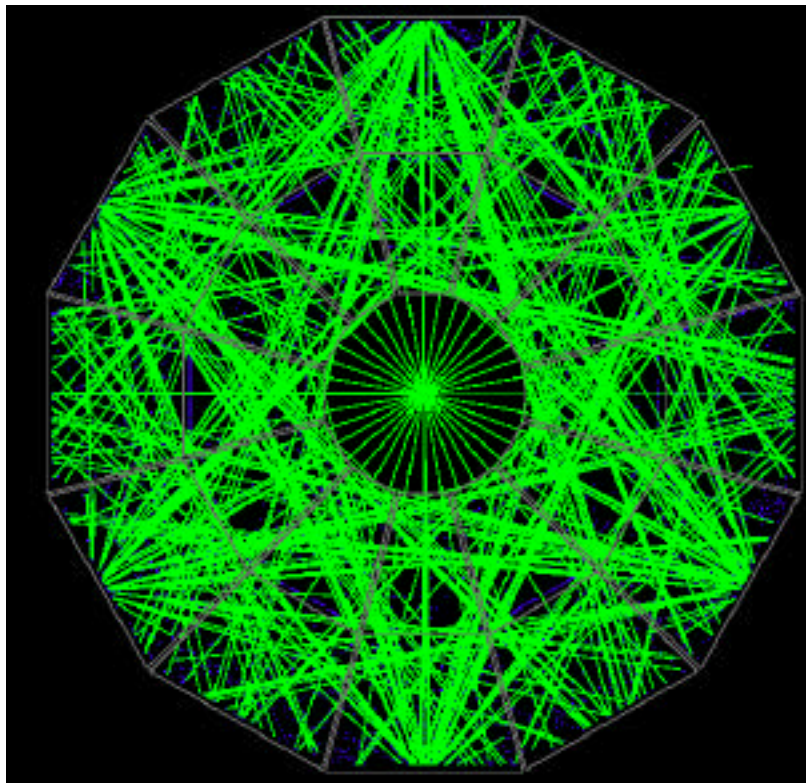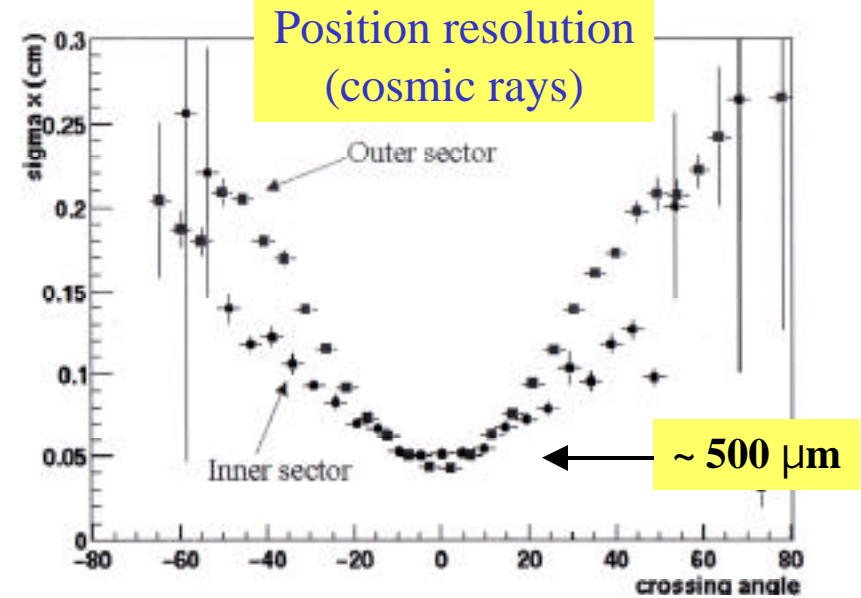
Momentum resolution dp/p (cosmics)

2-track-only events
opposite p$_z$
number of hits   30

○ Summer 99 (I. Johnson)
● Dec 99

p/p

CDR

p$_T$ (GeV/c)